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Exploring the Linkage between Land Use Type and Stream Water Quality of an Estuarine Island Applying GWR Model: A Case Study of Chongming, Shanghai

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Abstract

To understand the spatial correlations between land use type and water quality of an estuarine island is particularly essential to maintain its original ecological environment. Chongming Island is experiencing a rapid urbanization and agriculture land sprawl during the last decades, especially with the growth of agro-industry and the extension of old style residences. As a consequence, surface run-off from agricultural activities and domestic sewage discharge has a various linkage with stream water quality on the island. This study applied a geographical weight regression model approach to recognize the significance of the relationship between water quality and multiple land use. We also evaluated their spatial correlations which normally hidden from other traditional regression methods. The results reveal that the water quality of less-developed areas on Chongming Island was easily affected by land use types compared with other regions, TN, TP, BOD_5, COD were shown as the most significant responses among all the water quality indicators. Green land and water area had a reduced effect on nutrients, expansion of industrial land would continuously make a contribution of pollutants to the water environment. Suggestions should therefore be taken into consideration during the process of development planning, in order to prevent water contamination.

Keywords

Estuarine Island, Land Use, Stream Water Quality, Geographical Weight Regression

1. Introduction

As sustainable development is the main objective of management for small islands worldwide (Sandy A. Kerr, 2005; Tran, 2006; van der Velde et al., 2007; Romeela Mohee et al., 2015), maintaining the water environment under a healthy condition is an essential task to achieve the aim of sustainable development. However, issues like a plan-less urban sprawl, agricultural intensification, agro-industry, a lack of waste water control and treatment technique on small islands in China are threatening their own water environment and quality (Baorong Huang et al., 2008). Furthermore, stream water quality was easily affected by non-point source pollution generated by agricultural activity and domestic waste water, especially in rainy seasons, which is the period that represents a major risk against the water environment protection of the island. Under such circumstance, exploring the association between multiple land use types and stream water quality would provide important references for ecological planning and management for the islands.

Research concerning about stream water quality on an estuarine island has always been a key issue of the ecological environment protection on the islands. MARIE L. et al. examined a long-term water quality data set from the mid of 1980 to 1997 to study the trends of eutrophication on Western Long Island, trying to figure out the inducement. In 2010 Emily J. Shumchenia et al. assessed water quality in Rhode Island of Greenwich Bay in USA using evaluation of sediment profile imagery as the tool. Later on in 2011, Zhongyuan Yu et al. used a multiple-factor method to study spatial and industrial distribution traits and impact factors of water pollution on Hainan island. This study was aimed at discussing strategic ways to further building of eco-province on the island. Besides, many other studies on water quality of islands mainly focus on groundwater of volcanic islands, which discussed the effects of extra conditions such as climate change (Davood Mahmoodzadeh et al., 2014), surface soil (Syuntaro Hiradate et al., 2015) and sediments (Tatiana Cruz Fuentes et al., 2014) to ground water of the island. Researches concentrating on ground water of volcano island were relatively sufficient, however, there is a lack of studies focusing on the stream water quality and its corresponding impact factors of islands intervened by intense human activities. On a habitat island which is short of sewage treatment facilities, agriculture non-point source and urban point source pollution discharge have a significant effect on the stream water on the island and its downstream estuarine (Baker, 2003). Therefore, there is a missing of research on stream water quality of island associated with human settlements. Studying the influence of stream water quality of an island under anthropological development has important significance in protecting the ecological environment, as well as planning and implementing sustainable development of the small island (Ghina, 2003).

As spatial variations in land use type have affected the integrity and water quality of water resources, research on correlativity between land use type and stream water quality can provide valuable information for the development plan of the islands. For instance, many chemicals constitutes such as ammonia nitrogen concentration and chemical oxygen demand are affected both directly and indirectly by human land use activity (Bahar et al., 2008), which in turn cause water contamination problems, and potentially alter the ecological water environment. The relationship between land use type and water quality has been widely studied, discovering that stream water pollution is significantly related to agricultural non-point source pollution, discharge of industrial sewage and rural domestic waste (Ye et al., 2009). According to former researches (Dylan S. Ahearn et al., 2005; Roberts & Prince, 2010; María Laura Miserendino et al., 2011; Meneses et al., 2015; Songyan Yu et al., 2016), studying the influence of land use type on water quality is an effective and practical approach to predicting stream water quality trend in different scales of natural area. However, few researchers have explored the spatial relationships between land use type and stream water quality in a watershed on an island. Nevertheless, for some estuarine islands like Chongming which are close to a highly urbanized region, the land use type should have a major impact on its water environment and water resource. In addition, assessing the impact of land use type on islands is also an important subject faced by resource managers (Romeela Mohee et al., 2015). And this study will focus on figuring out the relationships between land use type and stream water quality of a habitat island.

Although many studies use conventional statistical methods such as ordinary least square (OLS) regression to address the relationships between land use type and alteration of water quality in different scales and places (Hejun Chang, 2008; Heidi Hertler et al., 2009; Guy Ragosta et al., 2010; Jinliang Huang et al., 2012; Meneses et al., 2015), this global regression lacks the ability to process relationships in local-specific area and spatial autocorrelation in model residuals (Songyan Yu et al., 2016). Besides, researchers found that different land use types have different impacts on water quality, and the relationship between a water quality indicator and a land use type may not constant over space (Jun Tu, 2011). In order to solve the inconsistency problem caused by spatial scale effects and watershed features, a geographically weighted regression (GWR) model, which has advantages for exploring the continuously spatial relationship variations over conventional global statistical methods was applied to examine the spatially varying relationships between land use type and water quality parameters (Fotheringham et al., 2003; Jun Tu et al., 2007; Jinliang Huang et al., 2015). An OLS model is also applied to compare the performance with GWR model.

This study aims at discovering spatial land use-water quality relationships of a human lived estuarine island in eastern coast of Shanghai (China) using 646 sampling data during the rainy seasons in 2011, as a deficiency of sampling sites in the whole study area has limitations on the effect of model simulation (Jinliang Huang et al., 2015). The GWR regression model was used for analyzing the impact of various land use types on different water quality parameters over space, and giving out the spatial relationship results. In order to examine which land use type can be applied as an important indicator to estimate and predict water quality, so as to improve the ecological management of land use of a scientific approach. Finally, the objectives of this study include: 1) discover the characteristic of spatial effect of different land use type of water quality of the island; 2) reveal the spatial relationship between stream water quality and multiple land use types; 3) discuss some general insights for island watershed management implications.

2. Study Area

Chongming Island is located in the Yangtze river delta, approximately 8 km off the coastal area of East China Sea at 121˚11'30'' to 121˚54'00''E longitude and 31˚27'00'' to 31˚51'15''N latitude (Figure 1). It has a major axis in the west-east direction. The island is the largest estuary alluvial island in the world which covers about 1200.68 km^2 land area with a history of 1300 years. In 2011, Chongming Island supported a population of about 703,722 including local and Outlanders. Chongming Island is situated in a subtropical zone with a monsoon climate, with a mean annual temperature of 15.3˚C. Its annual rainfall amounts to 1003.7 mm but 70.7% occurs in rainy seasons from April to September. It is characterized by a high density of river networks, fertile soil and relatively isolated environment with a long history of tillage. Besides, Chongming Island is ecologically sensitive as it is located in a boundary zone of ocean and estuary, which is close to a highly urbanized city area.

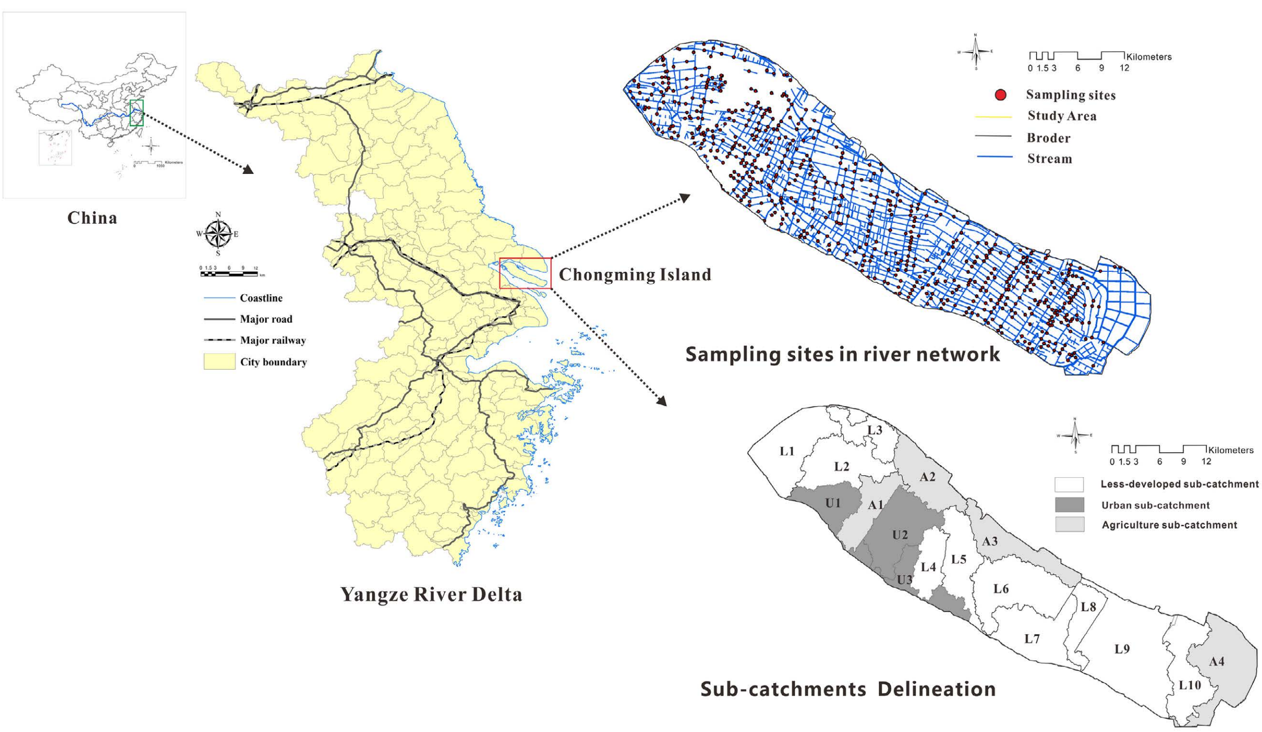

Figure 1. Study area and position of sampling points.

The island developed with agriculture based on the principle and supplemented by few manufacturers in a long term. Along with the construction of infrastructure and a local urbanization, industry gets a rapid speed of development. However, the development situation of agriculture will not change in recent years. Therefore, non-point source generated by agriculture and rural residence is assumed to be a long term problem. Beyond that, the island has to rely on the fresh water which is gained from the Yangtze river to fulfill the needs of lives. Thus, shortage of fresh water results in a high request for stream water quality inside the island.

3. Data and Methods

3.1. Data Sources

3.1.1. Water Quality Data

Water quality data of 2011 were obtained from Water Conservancy Management Office in Shanghai. The data were collected from the second water resource census of Shanghai. The whole process of surface water sampling and laboratory experimenting followed the Chinese National Standard (CSN) and also the International Organization for Standardization (ISO). Besides, the quality control procedures of laboratory work were also complied with CSN. Data from 646 water sampling sites were collected on the island, and the water quality parameters consisted of Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), ammonia nitrogen (NH_3-N), total phosphorus (TP), total nitrogen (TN). We have calculated the average value of each water quality indicator at each spot to ensure the veracity of the regression results.

3.1.2. Land Use Data

Land use data for 2010 were obtained from the Key Laboratory of Geographic Information Science of Ministry of Education, East China Normal University as the original land use data sources. Land use types of the original data set were reclassified into six categories by integrating: industrial, built-up, transportation, agriculture, green land and water area. We summed public green land, functional green land and forest land as green land in this study. Built-up land is summed as a percentage of public architecture, residential, commercial and recreational land. Water area is summed as rivers, lakes and ponds.

In order to make land use indicators and water quality sampling sites better corresponded, the study area has been divided into 17 hydrology sub-catchments using Arcgis spatial hydrological module, based on digital elevation data provided by Geographical Information Monitoring Cloud Platform, and then calculate land use indicators.

All land use indicators (percentage of each land use area) were calculated in Arcgis by overlapping land use and water quality indicators in the sub-catchment drainage area of every sampling site. Thus, the linkage of land use indicators for each sampling site and sub-catchment were established, then used for further analysis.

3.2. Regression Method

3.2.1. Geographically Weighted Regression

The geographically weighted regression (GWR) model is an extension of the ordinary least squares (OLS) regression model that allows parameters to be estimated by a multiple regression model (Fotheringham et al., 2003). Instead of estimating global parameters which ignores the coordinates of the observations, geographically weighted regression can generate a continuous surface of parameter values at each local observation to denote the spatial variations of the surface. This article aims to discuss the spatial influence caused by land use type on Chongming Island, using the method of GWR perform more pertinently and making spatial analysis fit the real situation. For the operation of OLS, we need to compare the accuracy of the results generated by two different regression models so as to testify the advantage of GWR in a spatial analysis.

GWR is a model associating variables with localized regression coefficient, it is based on kernel regression which allows various relationships to exist at different points in space (Antonio Pasculli et al., 2014). A typical GWR model can be written as follows:

$$y_i = \beta_0(\mu_i, \nu_i) + \sum_{i=1}^{k} \beta_i(\mu_i, \nu_i)\chi_{ij} + \varepsilon_i$$

where y_i denotes the dependent variable, in this case the value of water quality parameters at location *i*, μ_i and ν_i denotes for spatial point coordinates for each location *i*, $\beta_0(\mu_i, \nu_i)$ stands for the intercept coefficient at location *i*, χ_{ij} is the value of the *j*th explanatory variable at location *i*, $\beta_i(\mu_i, \nu_i)$ is the local regression coefficient for the *i*th explanatory variable. Besides, *k* is the number of independent variables, ε_i is the random location specific error term. All observations around sampling sites were weights using a distance decay function in GWR, with an assumption that the observations closer to the sampling sites have higher effects on local estimates for the site (Tu & Xia, 2008). In this study the adaptive bi-square nearest neighbor formulation was adopted as the weighting function of the GWR model, as the data points were distributed freely over the study area, and the optimal bandwidths was generated through minimizing the AICc (Akaike Information Criterion) to the lowest, which on behalf of a better model performance (Hurvich et al., 1998). The kernel shape is defined by following equation:

$$\omega_{ij} = \begin{cases} \left[1-\left(d_{ji}/h_j\right)^2\right]^2 & d_{ji} < h_j \\ 0 & \text{otherwise} \end{cases}$$

where ω_{ij} is the weight of observation *j* for observation *i*, d_{ji} is the distance between observation *j* and *i*, h_j is the kernel bandwidth which stands for the *n*th nearest neighbor distance from *j*.

GWR model generates a separate regression equation for each observation and provides a method to measure the spatial relationships between dependent variables and independent variables, assessing degree of spatial non-stationarity.

The regression results calculated by GWR model mainly include local parameter estimate value, the local R^2 value, t-test value of the local parameter estimates, and the local residual value. The local parameter estimate value was used to study the positive or negative relationships between variables, the local R^2 value reveals the situation of fitting optimization of the model, the t-test value was applied to examine the significance of the sampling points, and the local residual was used to calculate spatial autocorrelation of the model.

3.2.2. Spatial Autocorrelation Analysis

Spatial autocorrelation refers to the same variable in different spatial positions relevance, it can be divided into global and local indicators. Global Moran's I is calculated to detect spatial types throughout the study area which uses a single value to reflect the degree of autocorrelation of the study area. If a significant spatial correlation exists in an OLS or GWR model, then the model is probably to be invalid as it violates the assumption of randomly distributed and independent residuals in regression models (Rodrigues et al., 2014).

Moran index of model residual is one of the important indicators to test spatial autocorrelation. Moran index ranges from −1 to 1, the closer it reaches to −1 or 1, the more significant spatial autocorrelation the model has. Besides, the index reaches to zero indicates a spatial randomness (Antonio Pasculli et al., 2014) of the sample. This paper has calculated the global and local Moran index of residuals of each GWR and OLS model to evaluate the model's ability to deal with autocorrelation. Local Moran's I has been calculated for each spatial unit and the adjacent unit on the relevance of a particular property.

This study used spss 20.0 software to establish OLS model. GWR model was set up by GWR4.0 software, Global Moran's I and Local Moran's I statistics were carried out using Geoda software.

4. Results

4.1. Variation of Land Use Type and Water Quality among Sub-Catchments

According to variations of dominant land use type, the study area was divided into three categories, including urban sub-catchment, agriculture sub-catchment and less-developed sub-catchment so as to facilitate the research (**Figure 2**).

The land use varied among sub-catchment. In urban sub-catchment (U1, U2, U3) the total proportion of industrial land, built-up land, transportation land, has exceeded 22% of the sub-catchment, and in agriculture district (A1, A2, A3, A4) the percentage of agriculture land is more than 40% of the total area. Besides, the proportion of less-developed land (L1 - L10) which includes water quality and green land is beyond 63% of the corresponding sub-catchments.

The water quality of streams on Chongming Island generally met the requirements of landscape and recreation use set by surface water quality standard of Grade IV. However, spatial variations of water quality were found among different sub-catchments (**Table 1**).

The less-developed catchments had a lower concentration of DO and a higher COD, BOD, TP, TN, NH_3-N, than urban catchments and agriculture catchments. Compared to the standard concentrations of Grade IV, water quality parameters of DO, TP, TN, NH_3-N, had a higher exceeding rate than COD, BOD. Besides, the exceeding rate of DO, NH_3-N at the less-developed catchments (range: 65%, 63%) was higher than the urban catchments (range: 59%, 58%) and agricultural catchments (range: 59%, 59%). The results demonstrated that there was a potential risk of nutrient pollution in the less-developed catchments.

Normally, local parameter estimate (regression coefficients) of an independent variable of the GWR model is used to examine the level of dependent variable affected by independent variable. In this study, regression coefficients calculated by the GWR model were applied to analyze the relationships between land use type and water quality indicator at each regression point. Additionally, the

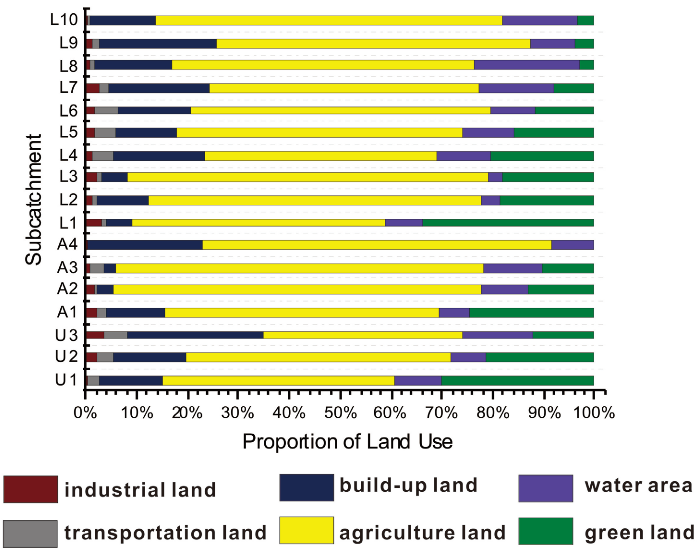

Figure 2. Land use proportion of Chongming Island.

Table 1. The variation of water quality parameters of different sub-catchment.

Water quality Parameters	urban sub-catchment		agriculture sub-catchment		less-developed sub-catchment		Grade IV	Exceeding rate (sub-catchment)		
	Mean	S.D.	Mean	S.D.	Mean	S.D.		urban	agriculture	less-developed
DO (mg/l)	2.934	1.85	2.9	1.62	2.8	1.84	3	59%	59%	65%
COD (mg/l)	24.11	7.58	20.94	6.12	22.5	21.79	30	13%	6.6%	9.8%
BOD (mg/l)	4.81	1.57	4.35	1.68	4.29	2.02	6	18%	7.7%	13%
NH_3-N (mg/l)	1.89	1.25	2.03	1.69	2.32	1.99	1.5	58%	59%	63%
TP (mg/l)	0.48	0.26	0.46	0.28	0.51	0.37	0.3	77%	58%	74%
TN (mg/l)	4.25	1.32	4.8	2.29	5.1	2.1	1.5	100%	100%	100%

local R^2 generated by the model was used to demonstrate the ability of the corresponding models to explain the spatial variance of model regression results. At last, the significance of the relationships was examined by t-test in the GWR models during estimates of the independent variable (Dylan S. Ahearn et al., 2004).

4.2. Performance of OLS and GWR Model

Generally, the local R^2 and AICc (Hurvich et al., 1998) of GWR were calculated to evaluate model performance. The increase of local R^2 of the model indicates a strong explain ability from independent variable to dependent variable. And AICc value was calculated to evaluate the accuracy and complexity of the regression model. A lower value of AICc of the model accounts for a better ability to predict (Wang et al., 2013).

In this study, we found that the performance of GWR model had a significant promotion compared with OLS model. As shown in **Table 2**, all local R^2 value of GWR models displayed much higher than OLS models, revealing a great improvement of model ability to better explain spatial variance of the independent variables.

AICc is another important parameter to assess the accuracy and precision of regression model. A comparison of AICc values between different models of the

Table 2. Coefficient of determination local (R^2) value of GWR models.

indicators		IN	TR	BU	AG	GL	WA
DO	R_G^2	0.36	0.034	0.392	0.174	0.282	0.059
	R_O^2	0.109	0.003	0.109	0.078	0.013	0.006
COD	R_G^2	0.292	0.039	0.389	0.181	0.668	0.053
	R_O^2	0.131	0.007	0.139	0.055	0.011	0.002
BOD_5	R_G^2	0.369	0.157	0.313	0.172	0.187	0.181
	R_O^2	0.012	0.021	0.16	0.002	0.02	0.015
NH_3-N	R_G^2	0.205	0.191	0.195	0.506	0.207	0.133
	R_O^2	0.001	0.01	0.002	0.216	0.026	0.054
TP	R_G^2	0.094	0.099	0.199	0.69	0.513	0.429
	R_O^2	0.001	0.005	0.001	0.102	0.211	0.124
TN	R_G^2	0.15	0.072	0.243	0.461	0.563	0.604
	R_O^2	0.013	0.045	0.001	0.142	0.234	0.147

Abbreviations: industrial land (IN), transportation land (TR), built-up land (BU), agriculture land (AG), green land (GL), water area (WA). R_G^2 denotes coefficient of determination value of the geographical weight regression, R_O^2 denotes coefficient of determination value of the ordinary least square regression.

same dependent variables provides a simple way to detect the superiority of the model, in which lower AICc value denotes that the model has a closer prediction result than the measured value (Tu et al., 2007). As shown in **Table 3**, improvements for all AICc values were observed for GWR models over OLS models in this study. All the t-test values of GWR model are shown to be significant ($p <$ 0.05) for different land use indicators with water quality parameters. Through the examination of AICc and local R^2, a significant advantage of the GWR model over OLS model was found, which was a guarantee for better accuracy of the GWR model.

The global Moran's I was calculated to evaluate the autocorrelation of model residual. Statistically significant positive spatial autocorrelation was found in all the OLS models with Moran's I value ranged from 0.098 to 0.695, which indicates the model violated the assumption of residual independence. In contrast, all GWR models had the global Moran's I ranged from 0.005 to 0.024, revealing a much better ability to deal with spatial autocorrelation compared with OLS model. (**Table 4**)

4.3. Variations of Spatial Relationships between Land Use and Water Quality

Relationships between percentage of each land use type and water quality had shown an obvious spatial non-stationarity according to GWR model results, which suggests that the relationship between land use type and water quality is

Table 3. Statistical test results of AICc value.

indicators		IN	TR	CO	AG	GL	WA
DO	**$AICc_O$**	2606.814	2610.943	2606.691	2612.609	2610.893	2609.691
	$AICc_G$	2593.869	2610.943	2590.206	2600.171	2594.77	2594.956
COD	**$AICc_O$**	5640.679	5636.487	5639.917	5640.644	5633.407	5639.778
	$AICc_G$	5626.058	5632.664	5620.169	5621.856	5621.066	5625.573
BOD_5	**$AICc_O$**	2707.845	2695.39	2707.382	2707.499	2696.1	2699.127
	$AICc_G$	2637.761	2640.716	2635.421	2638.789	2634.713	2637.694
NH_3-N	**$AICc_O$**	2183.28	2176.716	2179.108	2174.425	2177.265	2168.419
	$AICc_G$	2113.363	2118.291	2111.955	2124.125	2112.191	2138.119
TP	**$AICc_O$**	460.977	458.575	461.525	460.198	454.178	445.807
	$AICc_G$	438.738	436.137	433.649	437.398	436.743	430.908
TN	**$AICc_O$**	2832.433	2802.579	2832.072	2832.713	2810.558	2801.161
	$AICc_G$	2775.144	2788.017	2772.574	2469.801	2772.173	2782.695

Abbreviations: industrial land (IN), transportation land (TR), built-up land (BU), agriculture land (AG), green land (GL), water area (WA). **$AICc_G$** denotes the AICc value of the geographical weight regression, **$AICc_O$** denotes the AICc value of the ordinary least square regression.

Table 4. Moran's I of the residuals from GWR model.

indicators		IN	TR	CO	AG	GL	WA
DO	I_O	0.341	0.462	0.390	0.238	0.21	0.252
	I_G	0.207	0.122	0.122	0.094	0.061	0.242
COD	I_O	0.114	0.687	0.34	0.539	0.218	0.304
	I_G	0.127	0.159	0.123	0.212	0.137	0.135
BOD_5	I_O	0.185	0.155	0.261	0.202	0.366	0.409
	I_G	0.229	0.122	0.179	0.216	0.136	0.194
NH_3-N	I_O	0.231	0.587	0.208	0.385	0.264	0.439
	I_G	0.072	0.201	0.111	0.076	0.203	0.122
TP	I_O	0.317	0.348	0.695	0.535	0.434	0.209
	I_G	0.189	0.143	0.143	0.194	0.099	0.091
TN	I_O	0.326	0.281	0.098	0.189	0.210	0.103
	I_G	0.168	0.103	0.005	0.021	0.126	0.008

Abbreviations: industrial land (IN), transportation land (TR), built-up land (BU), agriculture land (AG), green land (GL), water area (WA). I_G denotes the value of Moran's I for residuals from the geographical weight regression, I_O denotes the value of Moran's I for residuals from the ordinary least square regression.

changing over space (Fotheringham et al., 2003). Land use indicators have both positive and negative relationships with all water quality parameters. But not all the relationships are significantly related.

For relationships between agricultural land and water quality, TN, TP, NH_3-N had higher significant levels than other water quality parameters. Nutrient of TN, TP, NH_3-N demonstrated a significant positive relationship ($p < 0.05$) with percentage of agriculture land in most of the less-developed sub-catchment. However, negative relationships were also appearing in agriculture sub-catchments, indicating the increase in the proportion of the agricultural land had little impact on the concentration of TN and TP (**Figure 3**).

Percentage of green land had a significant negative relationship ($p < 0.05$) with the concentration of TP in agriculture and less-developed sub-catchments (A1, A3, L3, L6, L7, L8), and positive relationship at A2, A4, L4, L5 sub-catchments. Meanwhile, the concentration of TN was negatively influenced by proportion of green land on both ends of the island area (L1 - L3, L8, L10, A4), but positively influenced by proportion of green land in agriculture and urban sub-catchments (A2, A3, U2, L7) (**Figure 4**).

Impact from built-up land on water quality was alleviated. As shown in **Figure 5**, percentage of built-up land presented significant positive relationships with a concentration of BOD_5 and COD mainly in the north area of the island (L1, L2, L3, L4, L5, L6, A1, A2, A3), suggesting that a higher percentage of

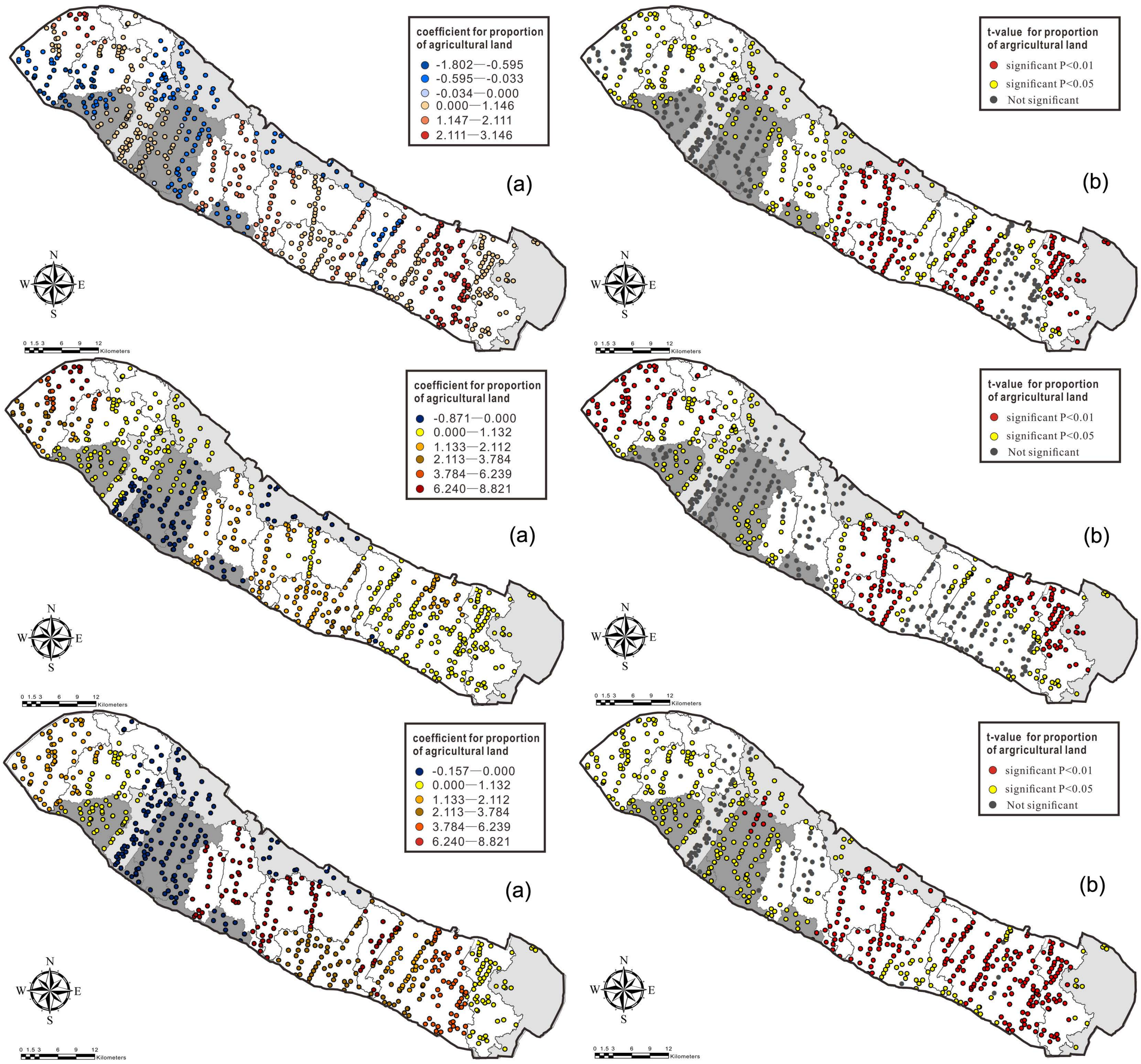

Figure 3. Results of the GWR model between percentage of agriculture land and water quality, from top to down: TP, TN, NH_3-N. Abbreviations: (a) local coefficients for water parameters and percentage of agriculture land; (b) significance distribution for water parameters and percentage of agriculture land.

built-up land relates to higher concentration of water pollutants in the corresponding area. On the contrary, parameters of BOD_5 and COD were negatively influenced by built-up land in south and the central area which basically consist of urban and less-developed sub-catchments (U1, U2, L7, L8, L9, L10).

The percentage of industrial land was found to be closely related to all aerobic organic pollutant water quality parameters than nutrients with an obvious spatial non-stationarity existed. Proportion of industrial land had significant positive relationships with a concentration of BOD_5 and COD at all urban sub-catchments in the north region (U1, U3) for most of the sampling sites. Same positive relationships were found in agriculture sub-catchments. In the mean

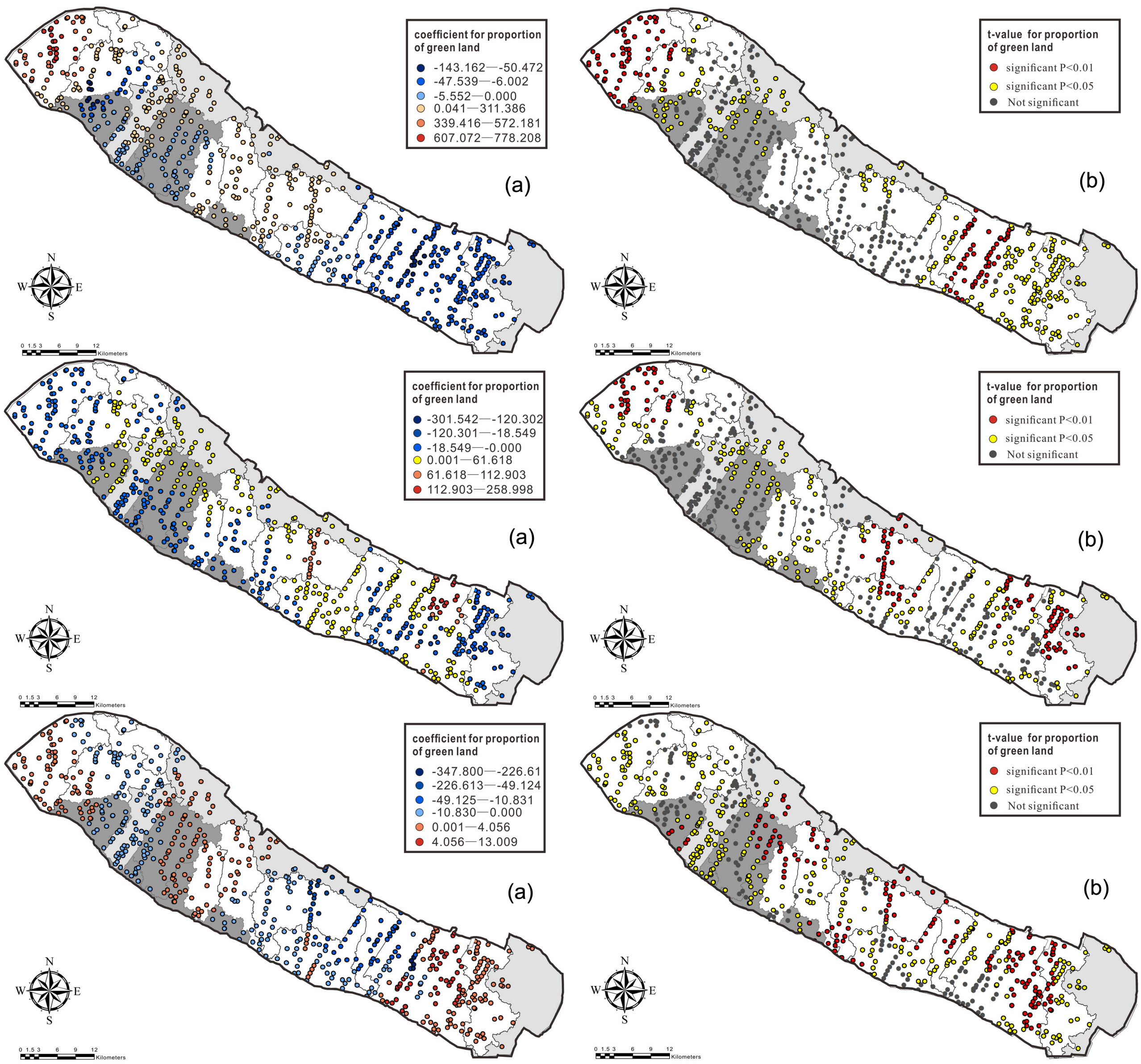

Figure 4. Results of the GWR model for percentage of green land with water quality parameters, from top to down: COD, TP, TN. Abbreviations: (a) local coefficients for water parameters and percentage of green land; (b) significance distribution for water parameters and percentage of green land.

time, correlation between percentage of industrial land and concentration of DO had revealed a significant negative relationship concentrated in all urban sub-catchments (U1, U2, U3), part of agriculture sub-catchments, and a large proportion of less-developed sub-catchments (A1, A2, L1 - L10).

Significant negative relationships were found between percentage of the water area and concentration of TP in the less-developed sub-catchments areas located in the southern and central parts of the island (L6, L7, L8, L9, L10). Similarly, the concentration of NH_3-N had a significant negative relationship with percentage of water area, which was also distributed in the central and southern parts of the island (L5, L6, L7, L9, L10).

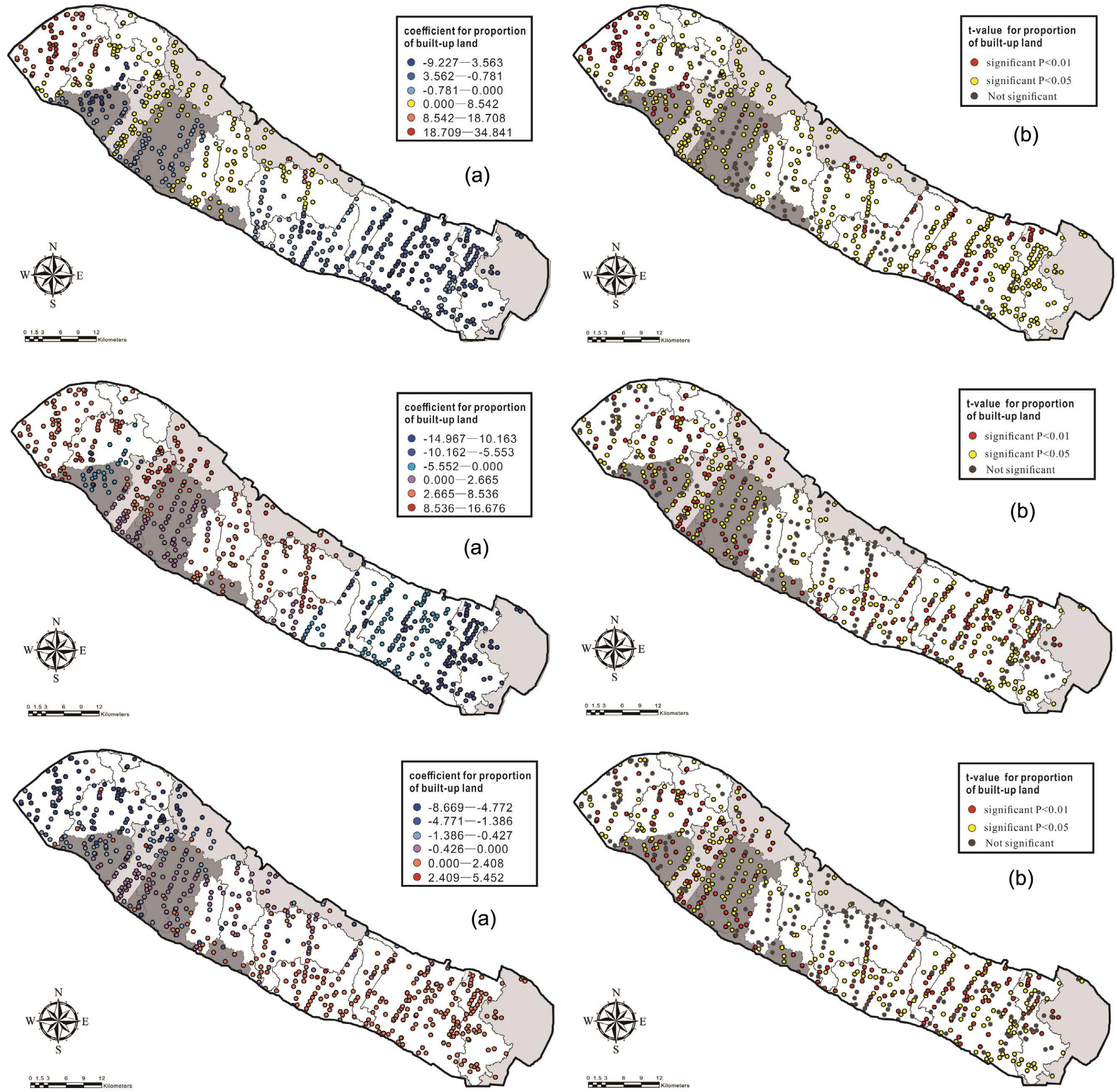

Figure 5. Results of the GWR model between percentage of built-up land and water quality, from top to down: BOD_5, COD, DO. Abbreviations: (a) local coefficients for water parameters and percentage of built-up land; (b) significance distribution for water parameters and percentage of built-up land.

5. Discussion

5.1. Explanatory Ability of Land Use Variables

Local R^2 is the fitting optimization between independent variables and dependent variables. Higher R^2 illustrates that an independent variable can explain more variance to a dependent variable. However, the meaning of the measurement equation is far more important than the statistical significance. As a relatively low fitting optimization of GWR model could also illustrate the relationships in a right way only if they have significance in environmental studies (Heidi Hertler et al., 2009).

The average local R^2 of all GWR models of this study is 0.27, which is relatively low compared with previous studies (Kibena et al., 2014), indicating that land use type could only account for 27% of the effect to stream water quality on Chongming Island (Qinghai Guo et al., 2010). Some researchers (Galbraith & Burns, 2007) also found that the explanatory ability of land use variables was less than 30%, with land use variables only contain composition of the land, meanwhile other studies covered configuration of land use type, geological and hydrologic indicators (Johnson et al., 1997; Sliva & Williams, 2001; Jun Zhao et al., 2015). The differences indicate that the explanatory ability on an estuary island is not only related to hydrologic factors and social economic level, but also to how many corresponding and water quality parameters are being considered.

5.2. Spatial Varying Effects from Land Use to Water Quality

Results of local parameter estimates, t-test, and local R^2 generated by GWR models allow the analyzation of the Spatial varying effects from land use to water quality parameters.

Agriculture land and Industrial land

Agriculture land was mainly associated with TN, TP, NH_3-N both positively and negatively over space. A positive significant relationship was found between the percentage of agriculture land and nutrients in less-developed areas. It means that an increasing of agricultural land proportion will lead to a high concentration of TN in stream water of the corresponding area. This is due to agricultural activities, including utilization of chemical fertilizer, livestock farming (Carpenter et al., 1998; Haidary et al., 2013; Lee et al., 2009; Sonoda et al., 2001; Sun et al., 2013; Tu, 2011; Wan et al., 2014) and excrement generated by aquaculture, were still the main source of total nitrogen and phosphorus (Carpenter et al., 1998; Jun Zhao et al., 2015) in the year of 2010.

However, the percentage of agriculture land also has a negative relationship with the concentration TN, TP, NH_3-N in agriculture sub-catchments (**Figure 6**), as in sub-catchments where the percentage of agricultural land has been already high, the change in proportion of agriculture land had little effect on water quality of nutrients.

In urban sub-catchments, the percentage of industrial land ranged from 0.1% - 3.6%, indicating that industrial development on Chongming Island was only in its primary stage, but industrial emission was an important source of water pollutants. According to the result of local parameter estimates, industrial land tends to have significant positive relationships with BOD_5, COD and a negative relationship with DO in urban sub-catchments, which agreed with some former studies (Evan J. Fedorko et al., 2004; Dylan S. Ahearn et al., 2005; Haidary et al., 2013; Lee et al., 2009; Pratt & Chang, 2012; Tu, 2013; Wan et al., 2014), as waste water discharged by factories from industrial park hardly meet the Chinese waste water treatment standard. Additionally, the local treatment plant has a

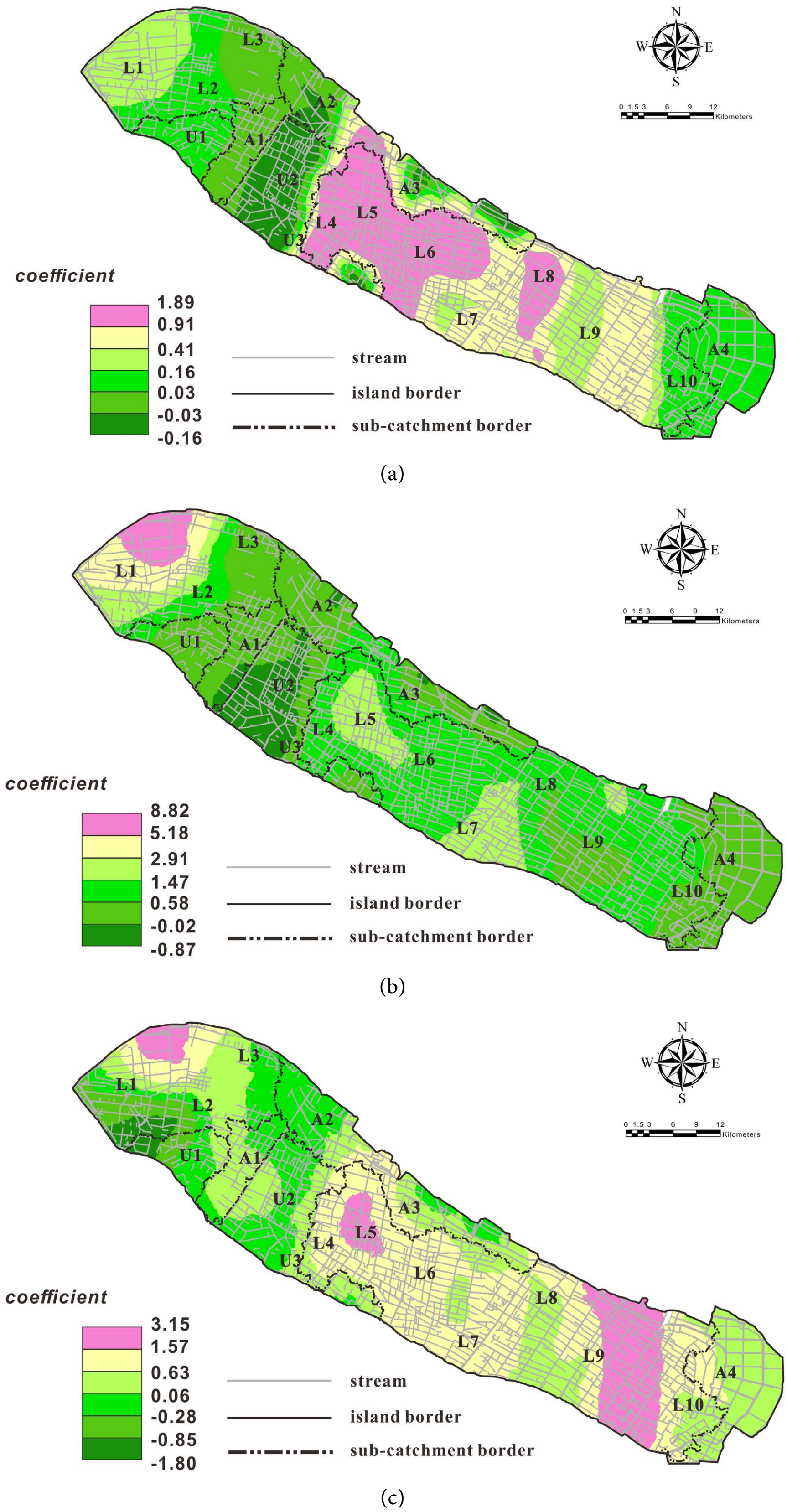

Figure 6. Prediction map: Kriging of all local parameter estimates of the GWR results between water quality parameters and agriculture land, from (a) to (c): TP, TN, NH_3-N.

deficiency on processing ability and capacity to treat a needed amount of waste water. Significant positive relationships were revealed between industrial land and concentration of BOD_5, COD in agriculture sub-catchments, which primarily attribute to expansion of agro-industry.

Green land and Water area

An increase of green land area could reduce the concentration of nutrients of water quality parameters, meanwhile both the concentration of COD, BOD, DO and TP, NH_3-N, TN will improve along with the increase of water area.

Green land is often associated with good water quality (Schoonover et al., 2005). The percentage of green land had shown a significant negative relationship with TP and TN in most of the less-developed sub-catchments, indicating a rise of green land proportion could reduce the concentration of COD and TP in stream water. Non-point source pollutants from agriculture activities had been sent into rivers and streams loaded by land run-off. During the period that run-off flow through grassland or forest land, nutrient molecules have been filtrated when they were affected by ecological processes, including soil adsorption, biological fixation of nitrogen from plants in green land and forest land (Sang-Woo Lee et al., 2009).

However, concentration of TN had shown a positive relationship with percentage of green land in some sub-catchments, reflecting a spatial different form GWR model. These results probably attributed to the contribution of fertilizer plants nearby (Water Conservation Bureau of Chongming, 2009).

The impact of water area on water quality was seldom reported in former researches. The analysis of GWR model results discovered that almost all water quality parameters had significant spatial relationships with the percentage of water area. TP and NH_3-N had negative relationships with water area in the south less-developed sub-catchments, while high percentage of water area were associated with lower concentration of COD, BOD_5 and DO. (**Figure 7** and **Figure 8**) Both of the corresponding sub-catchments had a low percentage of water area ranging from 2.7% to 9.2%. The local water environment assimilative capacity will be improved with the increase of water area, which might be the main reason why concentration of TP, NH_3-N, TN were negatively associated with the percentage of water area in the less-developed sub-catchments.

Built-up land

A clear spatial variance was found between the percentage of built-up land and water quality using GWR model. In contrast with the findings of previous research, high percentage of built-up land was not associated with bad water quality in urban sub-catchments and less-developed sub-catchments on Chongming Island.

Strong significant negative relationships between BOD_5 and COD and percentage of built-up land were found in south and north central area which basically consisted of urban and less-developed sub-catchments, and the results may have two primary cause. On one hand, Chongming Island had widely adopted the technology of rural domestic sewage treatment facilities before 2010, and the

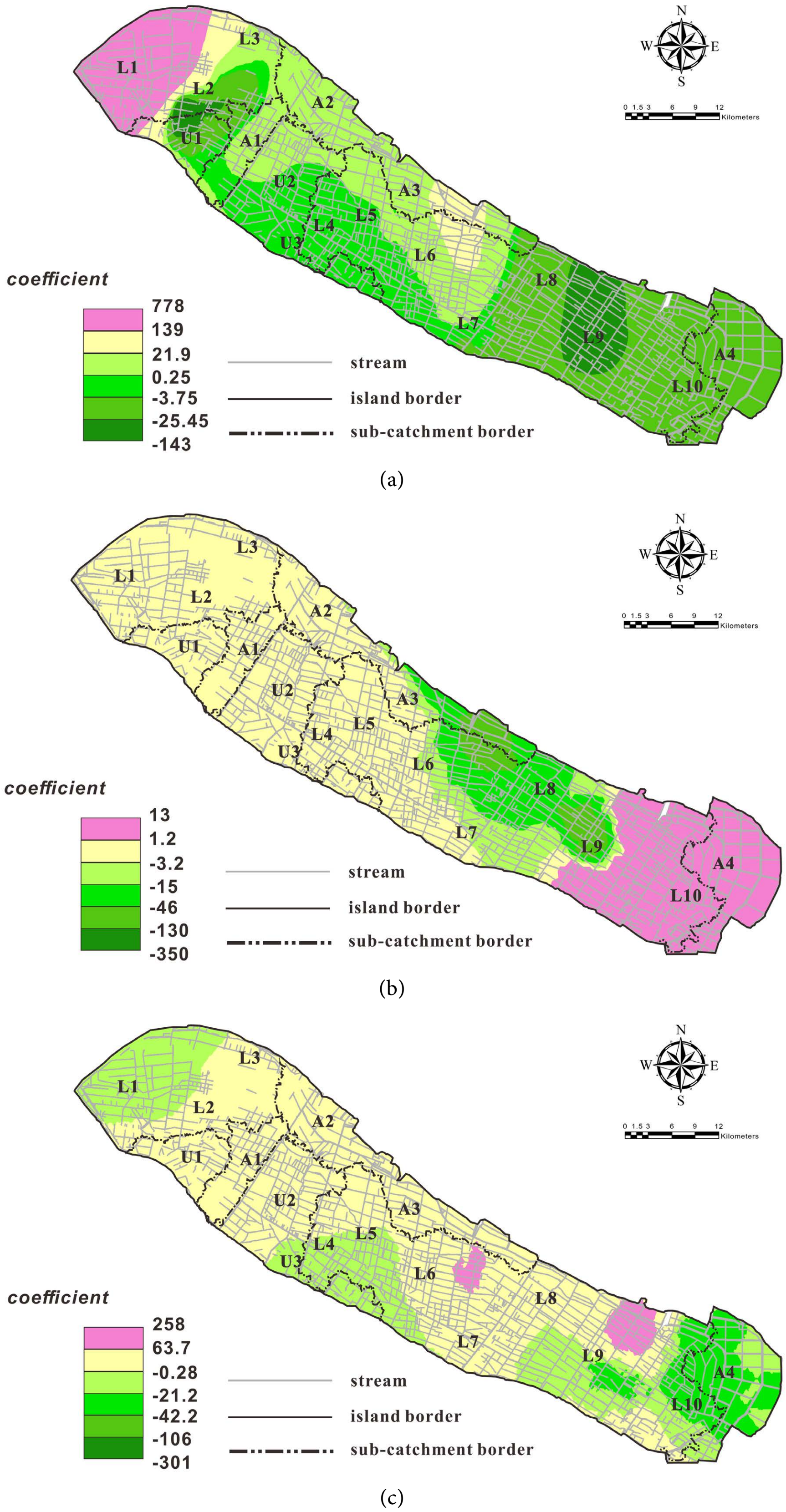

Figure 7. Prediction map: Kriging of all local parameter estimates of the GWR results between water quality parameters and green land, from (a) to (c): COD, TP, TN.

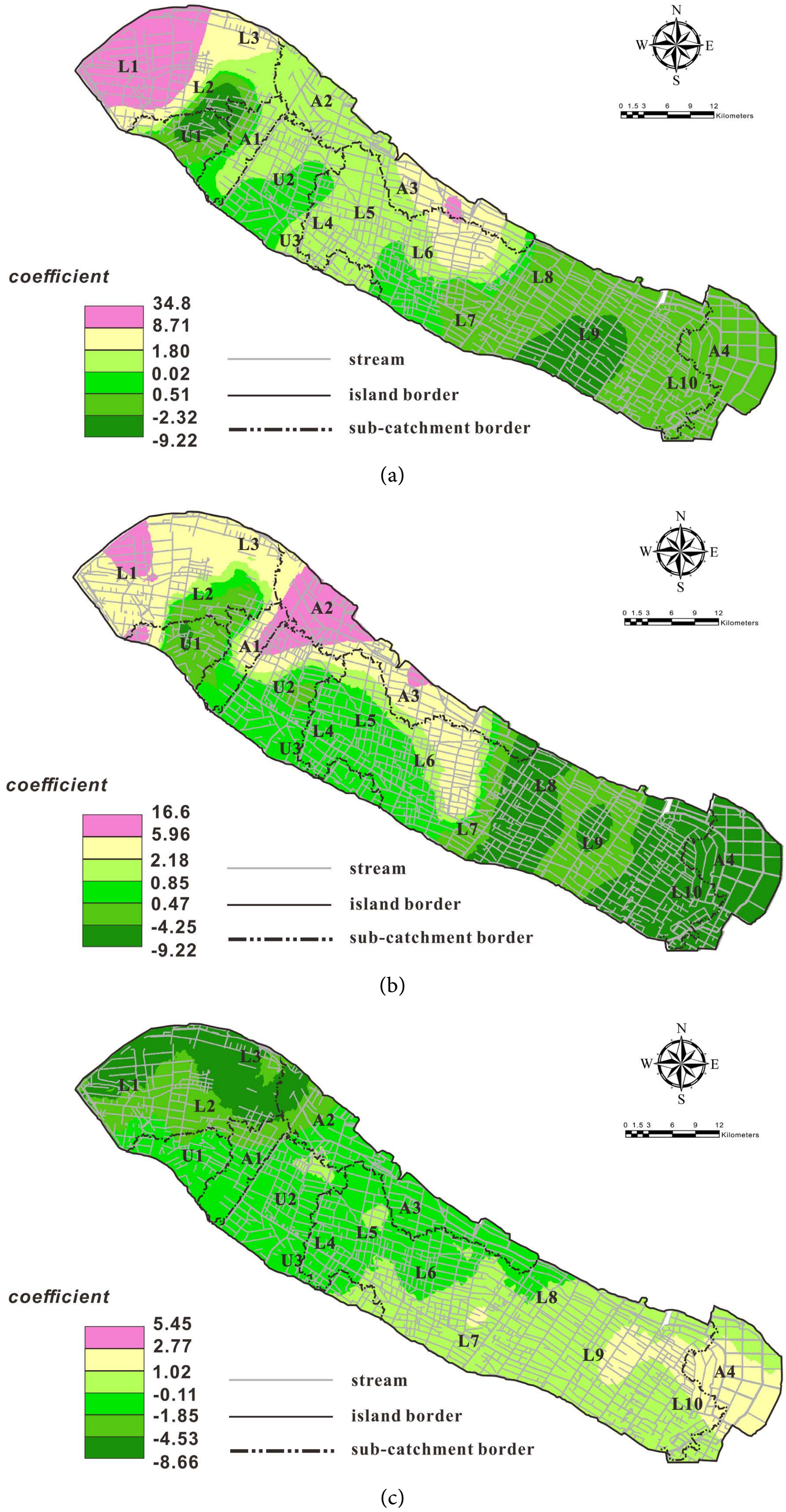

Figure 8. Prediction map: Kriging of all local parameter estimates of the GWR results between water quality parameters and built-up land, from (a) to (c): BOD_5, COD, DO.

treatment process works well at reducing the input nutrients generated by domestic sewage and rural livestock farming (Sheng Xie, 2013). On the other hand, in a sub-catchment where percentage of built-up land is low, it normally contains higher percentage of agriculture land and green land, which generates less water pollutants. As a consequence, high percentage of built-up land might not always associate with adverse water quality.

The GWR model results denoted that a lower percentage of built-up land was always associate with higher concentrations of BOD_5 and COD of stream water. In a sub-catchment where percentage of built-up is lower, it normally contains higher percentage of agriculture land and green land which generates less water pollutants. Therefore, high percentage of residential land might not always associated with adverse water quality.

However, in agriculture sub-catchments and less developed sub-catchments at the south of the island, the model results of built-up land and water quality had some significant positive relationships, which indicates built-up land still made certain contributions to non-point source pollution in those area.

5.3. Various Relationship between Land Use and Water Quality of Different Scales

This paper has simulated the spatial relationship between land use type and stream water quality of an estuary island on catchment scale, the results have many difference with most previous research (Dylan S. Ahearn et al., 2005; Haidary et al., 2013; Johnson et al., 1997; Lee et al., 2009; Pratt & Chang, 2012; Sonoda et al., 2001; Tu, 2013; Wan et al., 2014). The proximity at which land-use influences water quality has been studied in several different ways with varying results.

In some naturally upstream watershed scales, water quality of nutrients was strongly and positively related with built-up land (Sun et al., 2013). Meanwhile in coastal watershed scale, agriculture land was negatively correlated with nutrients of NH_3-N, TN (Jinliang Huang et al., 2013). Dylan studied the relationship between water quality and land use at a rural watershed scale showed that the proportions of built-up land including rural habitation and commercial land use had positive correlations to TN, TP, NH_3-N, COD concentrations (Dylan S. Ahearn et al., 2005). Besides, percentage of industrial land can't predict the loading of NH_3-N and TN. However, a combination of grassland and agricultural land plays an important role in driving the nutrient loading, which increased with increasing agricultural coverage. This relationship was also identified by our study.

In some highly developed watersheds, Johnson, Zhao had summarized that agriculture is no longer a pollution source but a container for pollution under the circumstances of rapid urbanization (Zhao, 2008). Christopher argues that urbanization had the strongest negative influence over water quality in different buffer scales of land use (Christopher P. Tran et al., 2010). Furthermore, Zhao found that urban land (built-up land, commercial land) had a positive relationship with most water quality indicators (TN, TP, COD_{Mn}, and NH_3-N) in metropolitan area, which is consistent with most previous research (Dylan S. Ahearn et al., 2005; Haidary et al., 2013; Johnson et al., 1997; Lee et al., 2009; Pratt & Chang, 2012; Sonoda et al., 2001; Tu, 2013; Wan et al., 2014).

Chongming Island wasn't deeply affected by human disturbance, and nor the upstream water. It was self-closed using sluice on stream connected to the sea. The urbanization and industrialization were still in its primary age. Although agriculture land use had the most important impact on water quality in this study, green land and water area had a negative impact on water quality. Particularly, green land and built-up land had a more complex relationship with water quality. Green land had a positive relationship with COD in water while built-up land was positively related with DO. This result had been confirmed by previous study (Dylan S. Ahearn et al., 2005). However, this relationship was only significant within the sub-catchment scale. When the scale size increased to the whole island, the correlation between industrial land use and water quality decreased.

5.4. Island Water Environment Conservation and Land Use Development Plan

This research has studied the spatial correlations between various land use types and stream water quality on an estuarine island, in which agriculture is the dominated land use type.

The application of GWR model results have provided specific references on protecting the stream water quality of the island: 1) a rapid development of agricultural activity and agro-industry in the past few years were the main sources of water pollution, 2) negative impact on water quality from built-up land had been alleviated after the popularization of domestic sewage treatment service, but it was still a pollution source in the southern less-developed area, 3) industrial emission still had important effects on water quality in urban regions and some agriculture sub-catchments, 4) water quality in less-developed sub-catchment was more vulnerable compared with urban sub-catchment and agriculture sub-catchment, 5) on the whole scale of the island, transportation land was not significantly related with water quality.

The protection of stream water quality of an estuarine island is a priority for island ecological conservation, as sustainable development is the main objective of management for Chongming Island. Few suggestions have been proposed for conservation of water quality on the island. Firstly, land use development plan should pay more attention to controlling the total amounts of agricultural activity and intensification of agro-industry, improving the efficiency of domestic waste water treatment, so as to reduce non-point source of contaminants. Secondly, the administrative department should restrict industrial growth in the conservation area, and ensure waste water from factories is strictly treated to meet the emission standard before it is discharged into the river. Finally, local development programs should enlarge the percentage of green land in urban and agricultural sub-catchments, and put river network protection job as the focus, especially in highly developed areas.

5.5. Limitations of This Study

This study attempted on applying a relatively large sample size in the GWR model application compared with former studies, (Christopher P. Tran et al., 2009; Huang et al., 2015) trying to figure out the spatial association between water quality and various land use types on Chongming Island respectively. Nevertheless, there were several limitations. On one hand, there is a lack of comparison between high and low run-off condition of the land surface, this study only concern about water quality in the wet season of the year 2011. On the other hand, the classification of sub-catchments in this article is an approach which mainly suits when illustrating effects of surface water quality from non-point pollution source. In sub-catchments where point source discharge was the dominated pollution source, the results of the model may be affected. Besides, this study haven't verified the temporary effect of land use change on stream water quality of the island, as only one year of the water quality and land use data were analyzed. Both positive and negative relationships appeared in some other sub-catchments, which might be affected by the sampling frequency and the way the sub-catchments had been divided.

6. Conclusion

In order to assess the spatial relationship between island stream water quality and land use type, we applied a geographically weighted regression methodology to analyze data collected from a river network of an estuarine island.

The characteristic of spatial effect from each land use type to water quality was evaluated by analyzing the results calculated by GWR model. We conclude that the water quality of less-developed sub-catchments at northern and southern parts of Chongming Island was regions which can be easily affected by land use types. Of all the water quality parameters are used to evaluate the impact from different land uses, water parameters of TN, TP, BOD_5, COD have shown the most obvious and significant responses.

The spatial relationship between land use type and water quality was evaluated through the local parameter estimate statistic analysis, which discovered that nutrients, mainly revealed positive and negative relationships with agriculture land and green land respectively. Meanwhile BOD_5, COD were positively related to industrial land and built-up land. Green land and water area had a reduced effect on nutrients in agriculture and less-developed area. Expansion of industrial land will continuously be a pollution source of the river simultaneously. Unexpectedly, built-up land denoted a negative impact to water quality in parts of the study area.

By the application of GWR model the character of spatial non-stationarity relationships and potential spatial differences between water quality and land use type was revealed, which could provide practical reference to island managers. In order to explore the effects from land-use to water quality, so as to protect the water environment of the island from been degenerated, further studies should be conducted in the future.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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